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METALS MATERIALS ENGINEERING IN TANK-AUTOMOTIVE EQUIPMENT

March 1968

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Materials Division

TACOM

VEHICULAR COMPONENTS & MATERIALS LABORATORY

U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

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METALS MATERIALS ENGINEERING
IN TANK-AUTOMOTIVE EQUIPMENT

by

Victor H. Pagano

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VEHICULAR COMPONENTS & MATERIALS LABORATORY

ABSTRACT

A special presentation was made before the Saginaw Valley chapter of The American Society For Metals on 12 March 1968. The paper presented materials engineering requirements peculiar to tank-automotive equipment which can be related to significant basic application factors to judge material suitability. These factors include weight, service durability, utilization, cost and ballistic integrity. Examples of prior and current development and application programs are described to demonstrate the importance of total materials analysis in tank-automotive equipment for achieving greater reliability, manufacturing simplicity and lower cost. Some of the topics covered are aluminum armor, explosive welding, explosive forming, application of leaded steels, and design around brittle fracture.

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INTRODUCTION

In the past year, Materials Engineering has become a topic for much discussion by many society members.

Although gradual, the transition from a society concerned with metals processing and application metallurgy to one concerned with overall materials engineering has been a very positive one as well as a logical one. Laboratory organizations have passed by natural course of events over the past 10-20 years from a testing and post mortem engineering group into a well knit group of specialists involved in basic equipment design.

The major function adopted by such laboratory groups has been that of material selection as part of the engineering design cycle.

Responsibilities have broadened also in areas of analysis and testing due to greater sophistication in materials know-how and laboratory tools.

A well organized and staffed group together with some oriented materials development activity can help effect optimum equipment design for maximum performance and reliability through proper selection of materials. Knowledgeable material selection can also lead to lower cost through lighter weight design together with simplicity of manufacture.

Thus, a materials engineering group is an operational activity responsible for the selection and application of proper materials and/or processes to provide functional, reliable and economic usage in all equipment design.

MATERIAL DESIGN CONSIDERATIONS

Tank-automotive equipment offers a challenging array of operational and environmental considerations for the materials engineer to cope with. For the tank, primary component areas include engine and power train, track and suspension, armament, and the hull and turret armor shells. For the logistic vehicle, there are the engine, power train, wheels and suspension, body and frame. Both types of equipment, because of cross country operational requirements, undergo severe conditions of loading for prolonged periods of time.

Aside from being subject to high dynamic and cyclic loads, military equipment must also sustain the effects of temperature extremes, corrosion, errosion and ballistic attack (projectile penetration and explosive shock) - under special circumstances, also radiation.

In the material to follow, a description of current efforts and case histories is made to show how various materials, processes and design methods are being investigated to overcome some of the operational problems associated with tank-automotive equipment.

INCREASED MOBILITY THROUGH LIGHTWEIGHT METALS DESIGN

Materials investigation for reducing equipment weight is a perpetual one in order to keep up with modern mobility concepts. This is especially true in tank design with its additional need for armor plating to protect against projectile attack and explosive blast. Successful application of lightweight metals for major vehicle components and for armor has helped the Army field improved combat and tactical vehicles.

Of significant importance has been the development and application of aluminum alloy armors. The first type used was work-hardened 5083 Mg-Al alloy applied to the M113 Personnel Carrier - a real workhorse in the current Vietnam conflict. Besides proven ballistic capability, aluminum armor has provided for easier fabrication by welding and higher integrity structural design.

A higher strength heat treatable aluminum armor has since been developed possessing improved ballistic properties with essentially the same ease of welded fabrication. The material is a Mg-Zn aluminum alloy identified as 7039. This material was primarily developed to overcome the special weight problems associated with the M551 Sheridan Vehicle. The 16-1/2 ton vehicle was designed for air drop operation and high degree of mobility with good small arms and fragmentation protection. It has an all aluminum armor hull and a steel turret. Use of aluminum armor on this vehicle was not without problems. The 7039 alloy is prone to stress corrosion cracking in the thickness or short transverse direction. Thus, usage required an appreciation of special design procedures to avoid application problems.

Besides lightweight metals for armor, similar use has been made to other component areas. As an example, consider the aluminum alloy forged road wheel (Figure 1) used on the M60E1 Medium Tank. The wheel is a 2014 composition aluminum alloy forging and weighs about 105 pounds, a saving of 50 pounds over the steel wheel for a total of 1400 pounds for the entire vehicle. Another significant area of light metal application was in the fuel tank (Figure 2). The tank is made from 1/4 hard temper 5086 aluminum alloy. This application saved 500 pounds over the old steel tanks. These weight savings applications were greatly responsible for making an improved and higher performance vehicle over the older M48 Medium Tank at the same 50 ton weight.

Also made and tested were parts from titanium alloy. Items included an escape hatch cover (Figure 3) and road wheel arms (Figure 4). Other items made were track parts, torsion bars, drive shafts and tow bars. From a weight standpoint, all were a success - 40% savings. Poor galling and wear characteristics have discouraged use in track part application.

Titanium has shown its best potential as armor. Based on projectile penetration tests of various kinds, titanium provides weight savings of about 20 to 25% over conventional armor type steels. As is true with the previously mentioned applications, the biggest barrier to the use of titanium is its high cost - $4.00 to $5.00 a pound - not currently recondilable to need.

In an effort to further reduce the weight of vehicles, work is continuing on other components. Typical of this is the concept for an all aluminum turret ring (Figure 5). This is the part which gives the turret directional control. In doing so, it helps carry the weight of the turret and related G-loads from gun firing and vehicle operation. The 80" diameter ring is made from a 7075-T6 aluminum alloy with an insert of hardened steel to form a non-brinelling surface for the ball bearings. The aluminum assembly weighs 274 pounds as compared to the steel assembly which weighs 667 pounds. Extensive road and firing tests at Yuma, Arizona, have indicated excellent application potential. Similar tests are currently planned for evaluating a 104" diameter aluminum turret ring.

Worthy of mention in solving the weight problem has been the application of magnesium alloys. Although limited, such materials are effectively being used to save weight. Particular use is being made in housings (transmissions and fans) and as floor decking. For example, a 55 to 60 pound AZ91C-T6 magnesium casting is used for the transmission housing in the Sheridan vehicle.

INCREASED SERVICE PERFORMANCE - WEAR RESISTANCE

In many of the light metal applications, wear resistance is usually an associated problem which crops up - for example, the aluminum road wheel. Steel wear plates are bolted to wheel inner flange surfaces to protect the aluminum against the sliding action of track center guides (Figure 6). Methods of dissimilar metal joining or bonding could help improve this design by eliminating the uncertainty of fastener failures or loosening. Explosive welding was selected and investigated for this application. Several wheels were successfully made for field testing. A new effort is currently in the making to optimize critical design features of the wheel forging consistent with efficient explosive welding.

In principal, the mechanism of explosive welding is a unique combination of physical phenomens involving high pressure mechanics and hydrodynamic flow. This phenomena is illustrated in Figure 7. Simply stated, bonding is accomplished when the high pressure developed by explosion is used to impinge metal surfaces in such a way that the metal surface can hydrodynamically flow as a spray of metal from the apex of the angled collision. This flow process and explosion of the metal surface is known as jetting. The severe shearing deformation and extension of the colliding surfaces by hydrodynamic flow and the resulting jet act to break up and dispense the bond inhibiting surface films, leaving film-free surfaces pressed into atomic contact, thus, constituting a metallurgical bond.

Figure 8 is a picture of explosively bonded steel to aluminum showing the wavy interface resulting from the metal jetting condition.

Another materials approach to achieving wear resistance in various metals is through hard coating or fuse coating (Tungsten carbide) processes. The merits of such a process is now being evaluated on selected wear areas found on steel track shoes used on the M113 vehicle (see Figure 9). If successful, it is believed that cracking problems associated with current induction hardening of selected part surfaces can be avoided. Tests required to insure a crack free product will also be eliminated. Use of lower carbon steels is also feasible.

IMPROVED UTILIZATION THROUGH NEW MANUFACTURING METHODS

Somewhat along the same line of explosive welding, since the energy sources are both from explosives, is our investigation on explosive forming of large armor components. The item chosen for demonstrating manufacturing adaptability is the steel turret of the Sheridan vehicle shown earlier. The intent of this effort is shown in Figure 10, i.e., simply to reduce the fabrication costs involved in the manufacture of this item. As currently planned, the turret will be made from two explosively formed parts - an upper and a lower half. The upper half presents the more difficult of the two halves due to several irregular shaped and variable thickness areas. Work is being conducted for us by both Aerojet General and North American. Based on work conducted so far, forming of the sections from higher strength armor steel should be fairly routine. A cost effectiveness analysis will be made of explosive forming and compared with the present method of welded fabrication.

LOW TEMPERATURE PERFORMANCE & DESIGN AROUND BRITTLE BEHAVIOR

The U.S. Army has had a long historical interest in the effect of cold environments on materials used in military equipment.

Most engineering materials show a substantial loss of useful properties at sub-zero temperatures. Although wood, ceramics and glass are virtually unaffected by extreme cold, the more important classes of engineering materials; namely, metals, rubber and plastics are indeed subject to mechanical failure.

The complexities of the brittle fracture problem and controlling factors can be shown to some degree in the concept of transition temperature. This is the temperature below which a material behaves in a brittle manner. The commonly used test method for determining transition temperatures and evaluating toughness of metals is the V-notch Charpy impact test. The transition temperature depends on a variety of metallurgical and mechanical factors; however, some qualified generalities can be seen in Figure 11 regarding susceptibility to brittle behavior.

The application of the transition temperature approach to design is more complex than for just simple comparison of materials. In design, the ultimate question evolves around the load bearing capacity of the structure or member for the prevailing circumstances and the relationship of transition temperature to load bearing capacity. A general concept, which has come into wide acceptance, is that for temperatures above the transition temperature, stresses of the order of the yield stress may be tolerated, and below the transition temperature, the applied stress must be kept to some unknown low level.

A more definitive approach which is growing in acceptance and actual use is the fracture mechanics or fracture toughness approach developed from the Griffith concept by Irwin and associates. It applies to design situations involving sharp notches or defects which would not be detected by normal inspection procedures. The essence of the concept is to relate the stress for fracture and the material properties to the size of a sharp notch or defect. Figure 12 provides a graphical illustration of the relationships of stress, defect size, and toughness for the case of a small disk shaped crack embedded in a large tensile stress field. By inserting the toughness (G_{IC} - critical crack extension force, in lbs/in^2 or K_{IC} - critical stress intensity factor, psi $\sqrt{in}$) and the defect size numbers in the appropriate mathematical expressions one can solve for the critical value of the stress which will cause catastrophic fracture. Conversely, knowing the toughness and applied stress, it is possible to estimate the

critical defect sizes that are required for catastrophic failure. Design based on the assurance of at least some degree of notch toughness is far better than design based on the assumption that a structure is completely devoid of defects.

Efforts both under contract and in-house have been implemented by USATACOM to accelerate the appreciation of this approach for application in design of equipment. In the near future, it should eventually be possible to select materials which are adequate for a critical structural application in a given climatic environment, or to specify a minimum acceptable value of toughness for marginal material.

IMPROVED UTILIZATION THROUGH BETTER DEFINITION OF MATERIAL PROPERTIES

Resolving questions of utilization are often necessary through special studies especially where differences in material performance have been recorded. This has been the case with leaded steels.

In the thirty years since the beginning of quantity production of leaded, free-machining steels, their use in low strength applications has grown steadily. However, a number of service failures were encountered during the developmental period for leaded steel melting practice, which were traced to a metallographically "dirty" structure. In one instance, the presence of a lead inclusion near the surface of a diesel injector nozzle resulted in failure due to the melting of the inclusion. Current practices for adding lead have essentially eliminated the early processing difficulties caused by gross lead segregations.

The use of lead in alloy steel is relatively recent, and the number of applications for this material is increasing. There has been, however, some resistance to their use in high strength applications because of catastrophic failures which have occurred during heat treatment or subsequent processing. Several examples will serve to illustrate this situation.

A heat treating firm, experiencing heretofore unknown cracking in a spindle subjected to warm-punch straightening after heat treatment, determined that the only change in practice was that a leaded 4140 type had been substituted for the non-leaded alloy used previously.

Manufacturers of heat treated gears with flame or induction hardened teeth found extensive radial cracking in a leaded alloy steel grade after the hardening treatment. Expansion of the teeth during the surface hardening subjected a region just below the surface to high tensile stresses. This, coupled with a "forbidden" range of temperature, caused the failure. Failure point was found to originate at the site of a lead inclusion.

The failures all had a common factor; at some time during processing or service the leaded part is subjected to stress at an elevated temperature.

Although the effect of lead on mechanical properties seems relatively minor, the disparity between the mechanical properties of leaded alloy steels reported in the literature on the one hand, and the service failures traced to changeover to a leaded steel type on the other, suggested a closer look at the elevated temperature properties of a leaded and non-leaded grade of 4145 steel. Such an effort was undertaken under contract with Illinois Institute of Technology.

At approximately the lead melting point (621°F) or somewhat above, the leaded steels (140 KSI) showed 50 to 60% less ductility than the non-leaded material. Even more spectacular is the complete loss of ductility at strength levels of 200,000 psi between 600° to 800°F (see Figure 13).

Design application must, therefore, consider this embrittlement condition if practical usage is to be made of these steels.

PROVEN MATERIALS & METHODS - NOT ALWAYS A PRODUCTION REALITY

There are times, too, where proven materials cost savings efforts do not materialize for lack of adequate response from industry. Two developments stand out as good examples. The first was the satisfactory development of induction hardening procedures for heavy duty tank gearing (Figure 14). The hardening profile pattern for the gear is shown in Figure 15. Besides offering a tenfold increase in production rate, induction hardening improved dimensional stability and eliminated need for high alloy steels. Since its addition to drawings in 1957 for both process and materials as an alternate method to carburizing, not one production gear has been made by the induction hardening method.

A similar situation was experienced with the precision casting of the M48 tank drive sprocket by the graphite mold process in lieu of fabricating from steel plate. A comparison of both methods of manufacture is summarized in Figure 16. The differences are obvious and the savings quite significant. However, the molded part still remains to be made under a production order.

In conclusion, functional equipment of any kind is best evolved out of a combined consideration of good design and modern materials.

Where this fundamental thesis is practiced to the fullest, functional and reliable products will be found along with good economy.

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11. Various In-Progress Contract Work (1968) by USATACOM:

    a. Explosive Forming Large Armor Components, Aerojet-General Corporation & North American Aviation, Incorporated, Contract Nos. DAAE-7-67-C-2405 and DAAE-7-67-C-5727 respectively.

    b. Hard Coating of T130 Track Shoes, Contract No. DAAE07-67-C-5592.

ALUMINUM ROAD WHEEL FOR M60 TANK

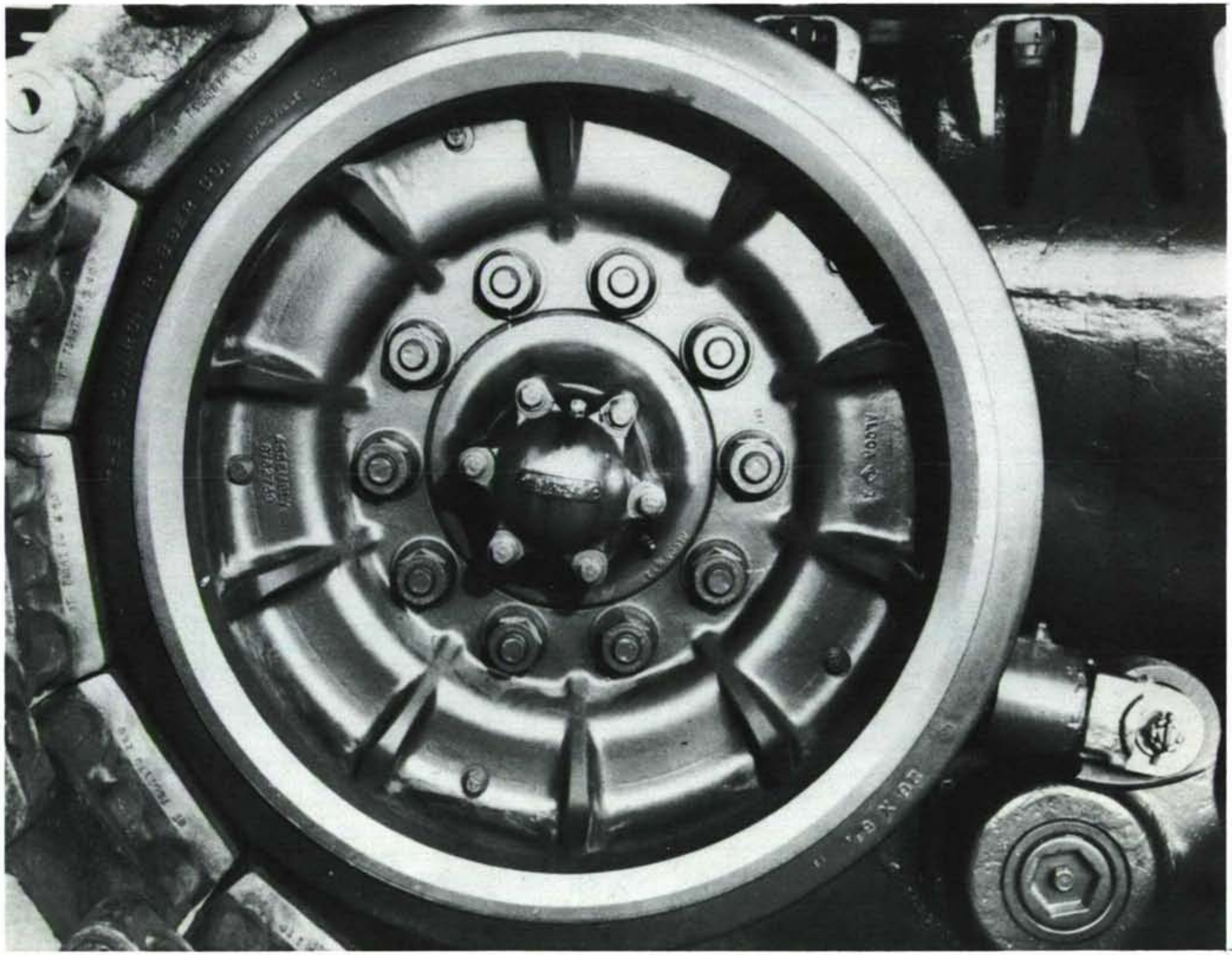


FIGURE 1

ALUMINUM FUEL TANK FOR M60 TANK

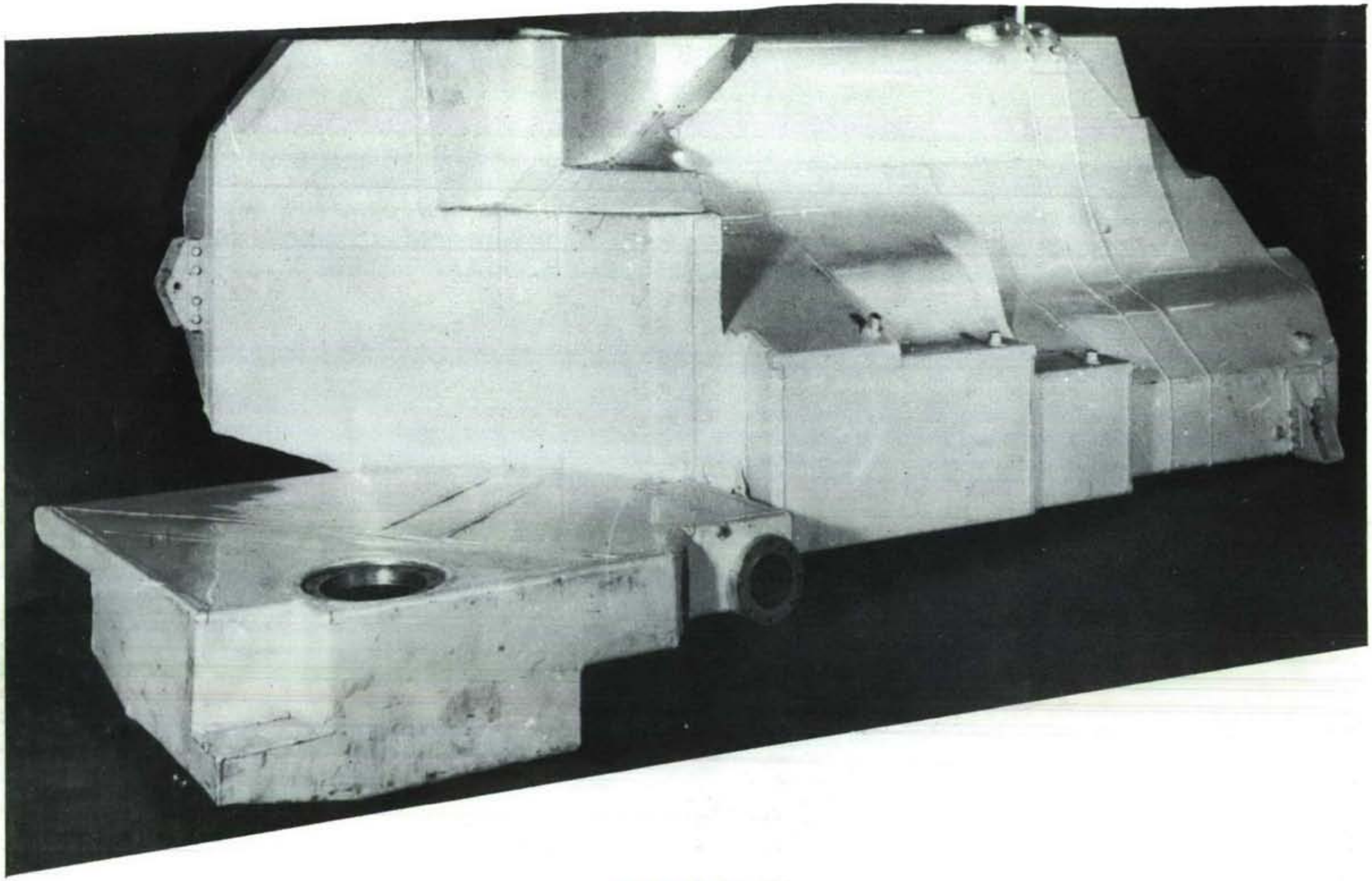
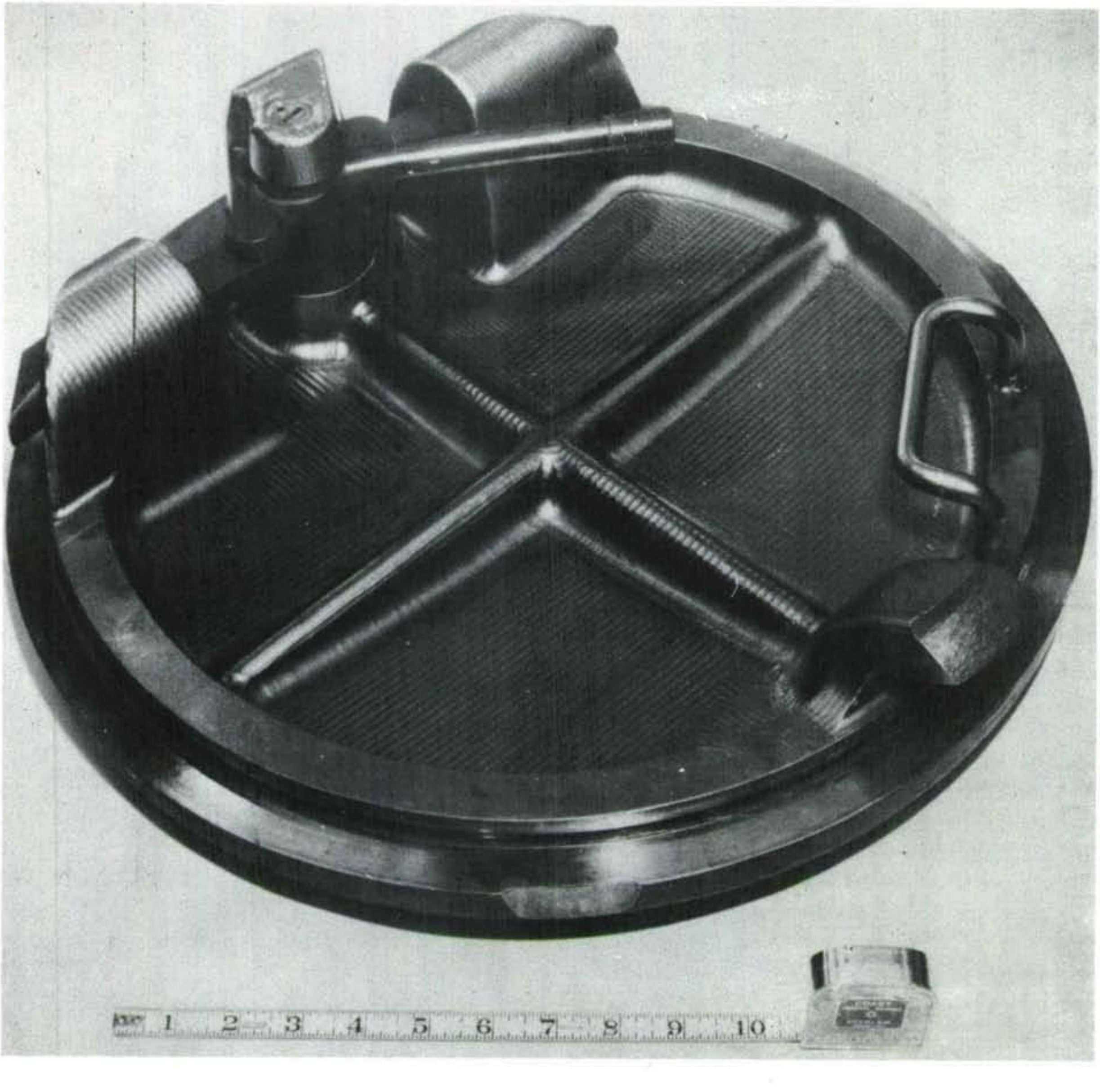


FIGURE 2

FORGED TITANIUM ESCAPE HATCH COVER



WT. STEEL	APPROX.	130 lbs.
WT. TITANIUM	APPROX.	78 lbs.
WT. SAVINGS		52 lbs.

FIGURE 3

FORGED TITANIUM TANK ROAD WHEEL ARMS

INTERMEDIATE ROAD WHEEL ARM			IDLER ARM			FRONT & REAR ROAD WHEEL ARM		
WT	STEEL	137 lbs.	WT.	STEEL	137 lbs.	WT.	STEEL	162 lbs.
WT	TITANIUM	76.5 lbs.	WT.	TITANIUM	76.5 lbs.	WT.	TITANIUM	90.5 lbs.
WT	SAVINGS	60.5 lbs.	WT.	SAVINGS	60.5 lbs.	WT.	SAVINGS	71.5 lbs.

FIGURE 4

ALUMINUM TURRET RING

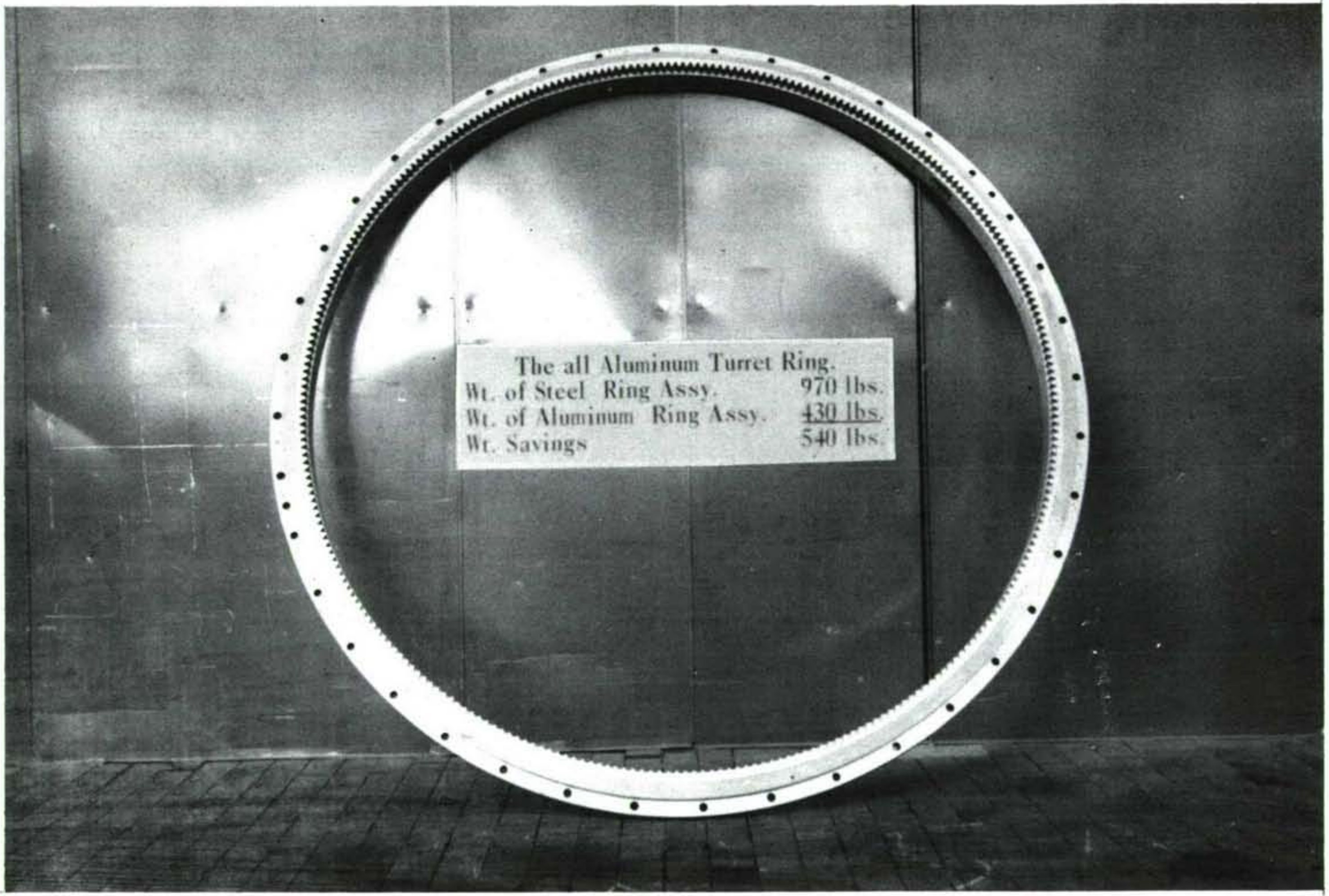


FIGURE 5

ALUMINUM WHEEL DESIGN WITH BOLTED WEAR PLATE

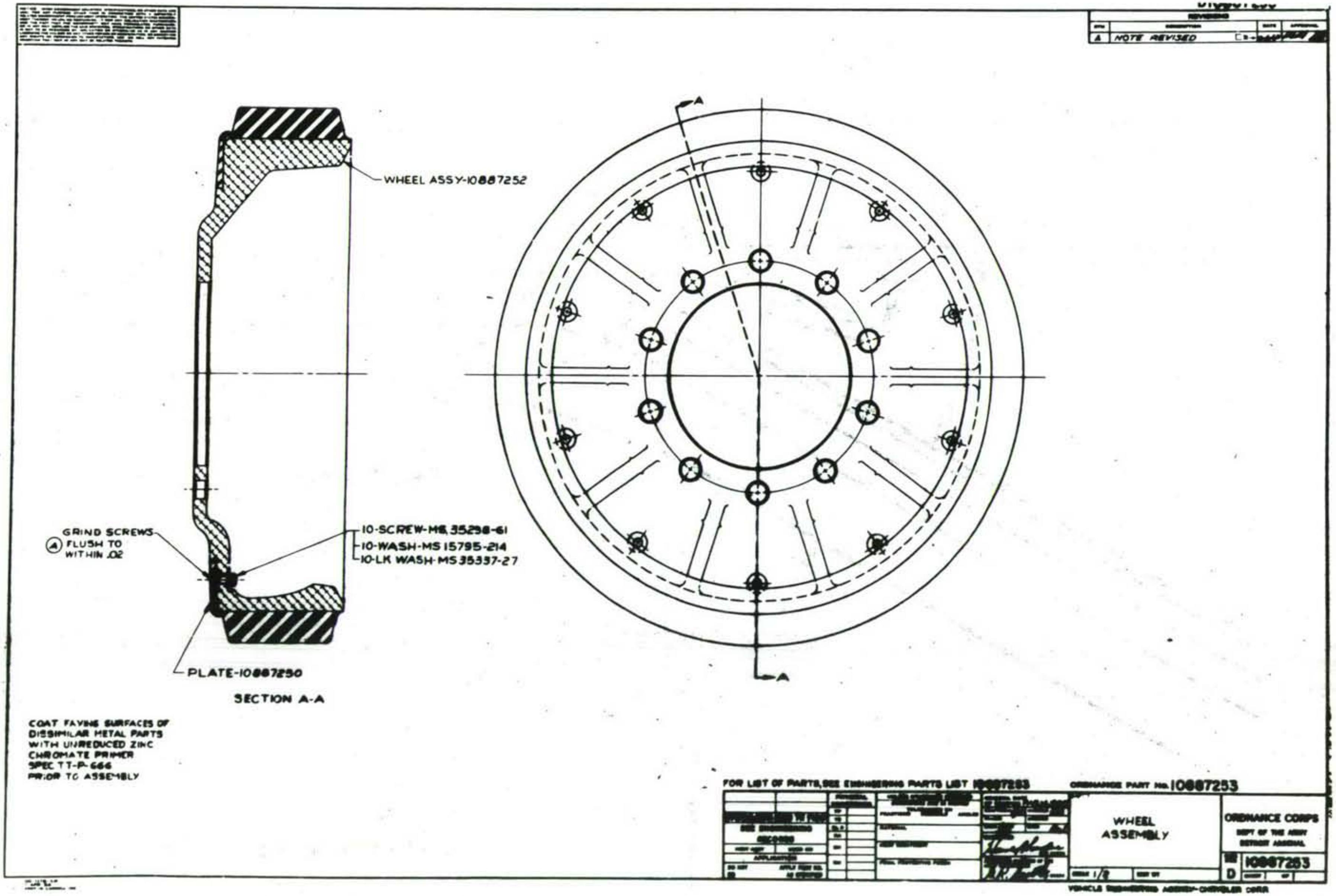


FIGURE 6

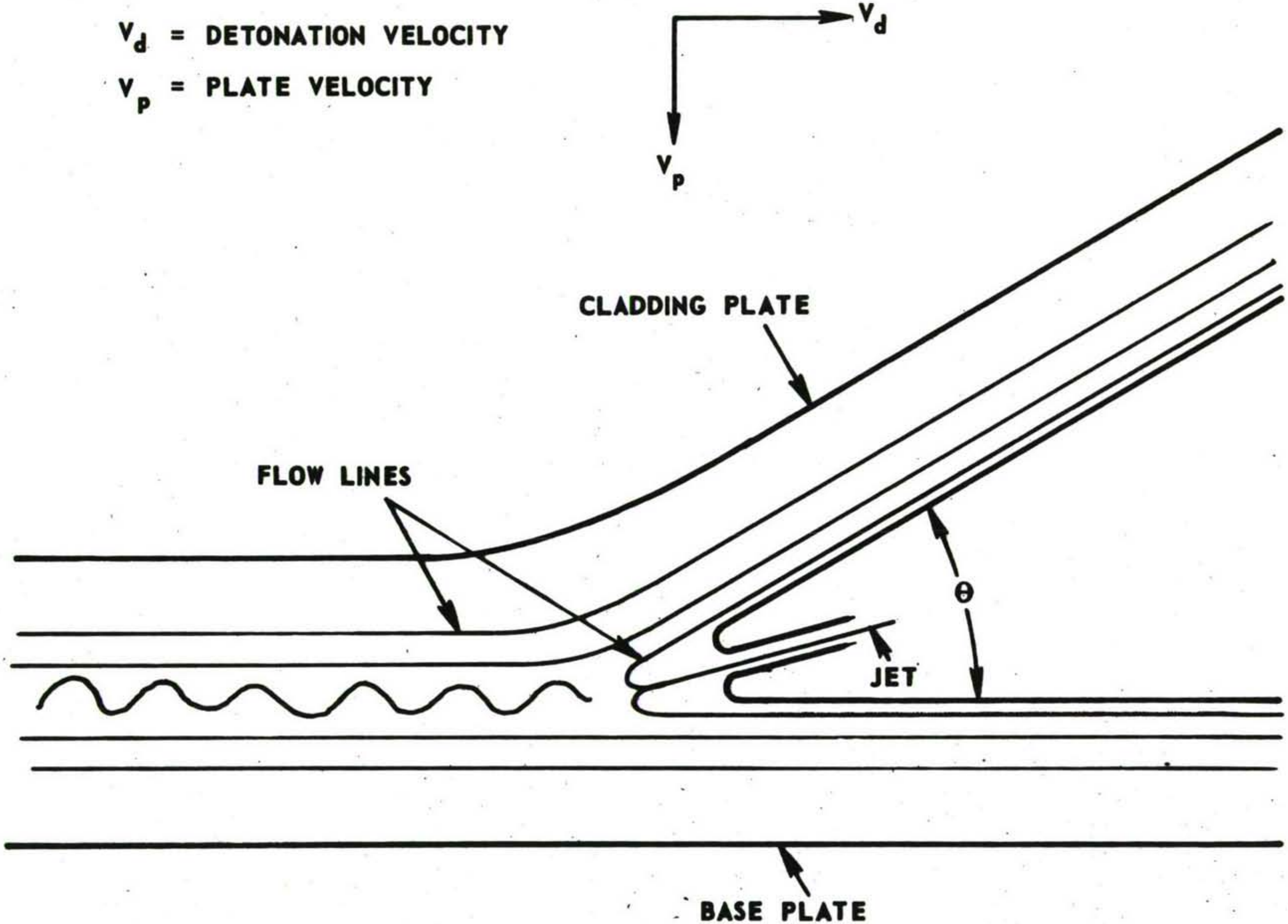


FIGURE 7 ILLUSTRATION OF PLATE COLLISION PROCESS AND RESULTANT JETTING PHENOMENON DURING EXPLOSIVE BONDING

ENLARGED VIEW OF EXPLOSIVE WELDED JOINT

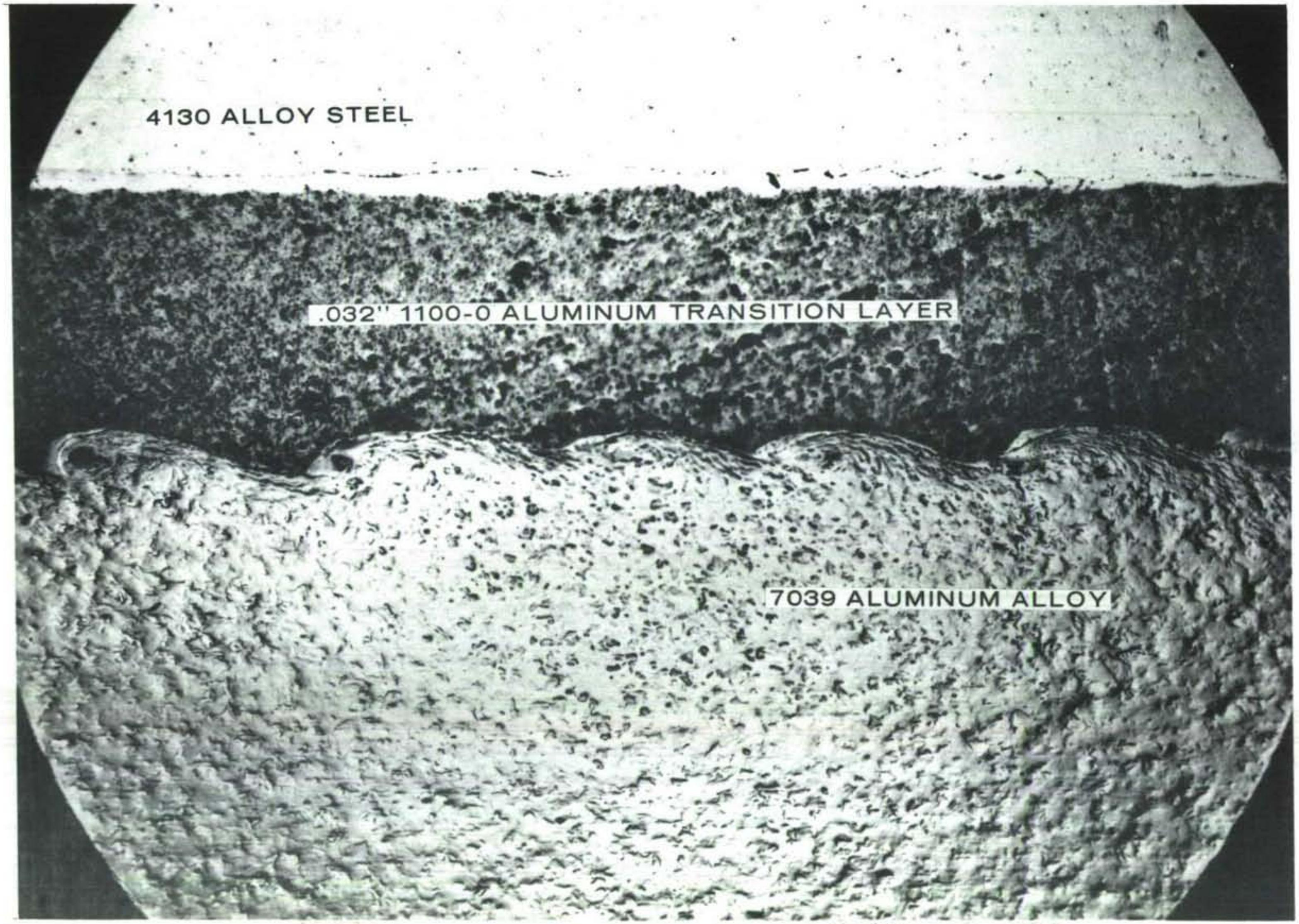


FIGURE 8

MANUFACTURING PROCESS/TECHNIQUES FOR HARD FACE COATING OF STEEL COMPONENTS

FIGURE 9

OBJECTIVE:

- To develop a method of hard facing of steel components whose wear surfaces are presently hardened by the induction or flame hardening process.

DESIGN OF EXPERIMENT:

- Selection of test item — T130 Track Shoe.
- Substitution for induction hardening — fusing of carbides on wear surfaces.
- Improvement of fatigue properties — tuftriding.
- Control specimens — current production.

ADVANTAGES OF FUSE COATED CARBIDES OVER CURRENT INDUCTION HARDENING PROCESS:

- Low capital equipment investment.
- Economically applied in production.
- The exacting controls for heating and cooling cycles are not required. Thus, the cracking tendency of the hardening wear surface is eliminated thereby the inspection controls are unnecessary.
- A component may be fabricated from lower carbon/alloy steel.

FORMING LARGE ARMOR SECTIONS

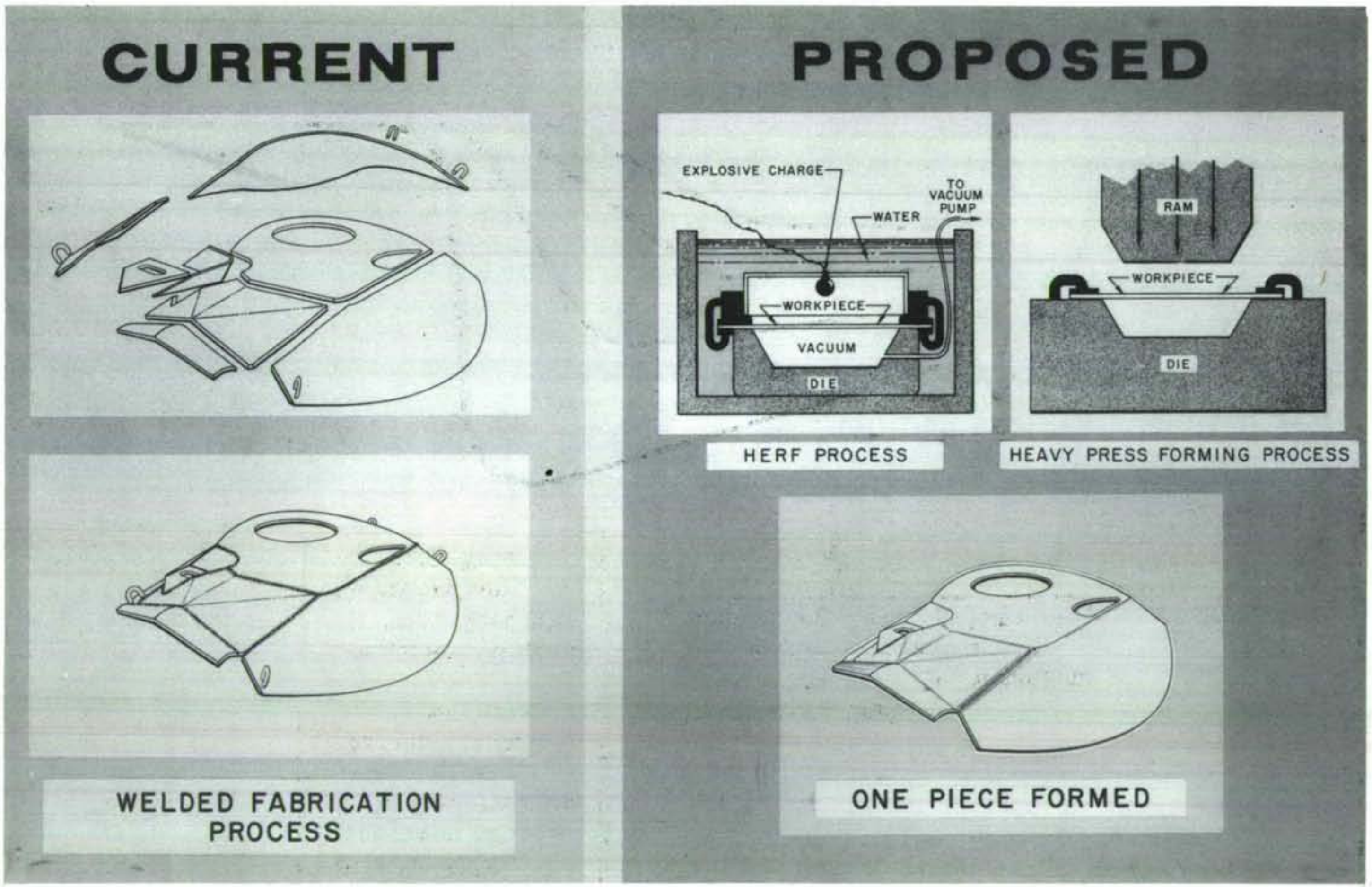


FIGURE 10

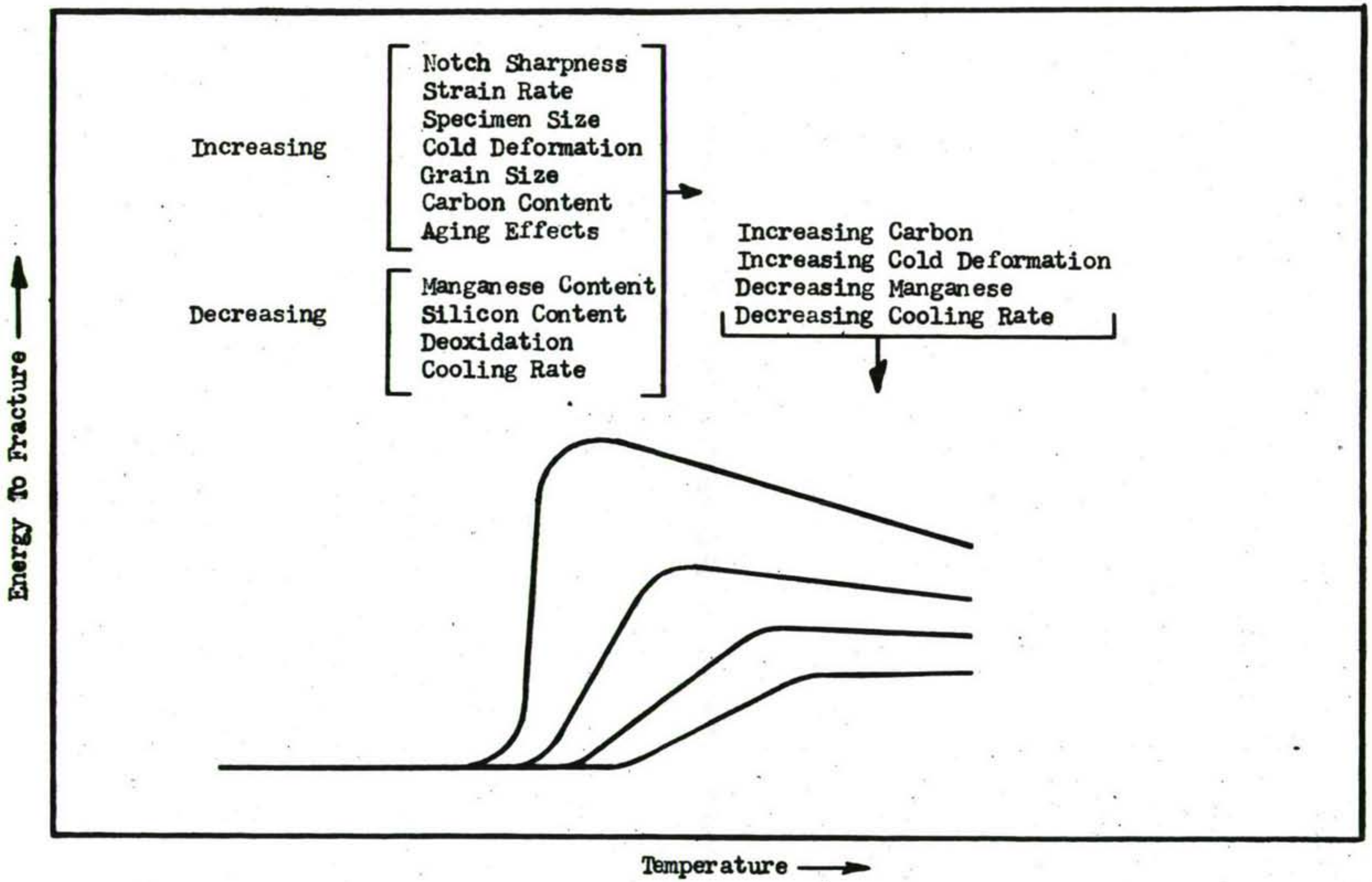


FIGURE 11 Effect of Mechanical and Metallurgical Properties on the Fracture Characteristics of Steel

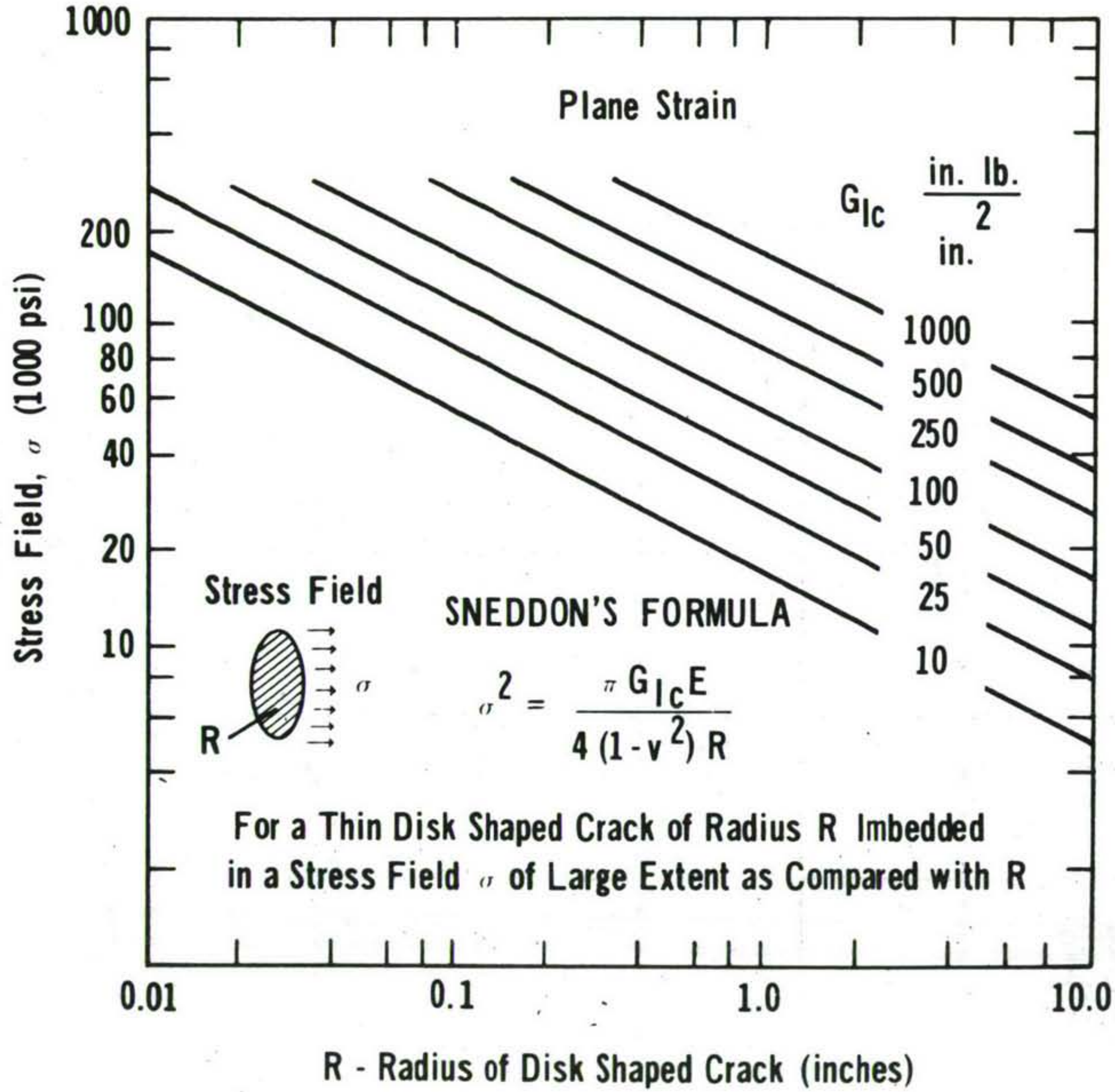


FIGURE 12 The relationship of fracture strength-to-crack size for different levels of fracture toughness

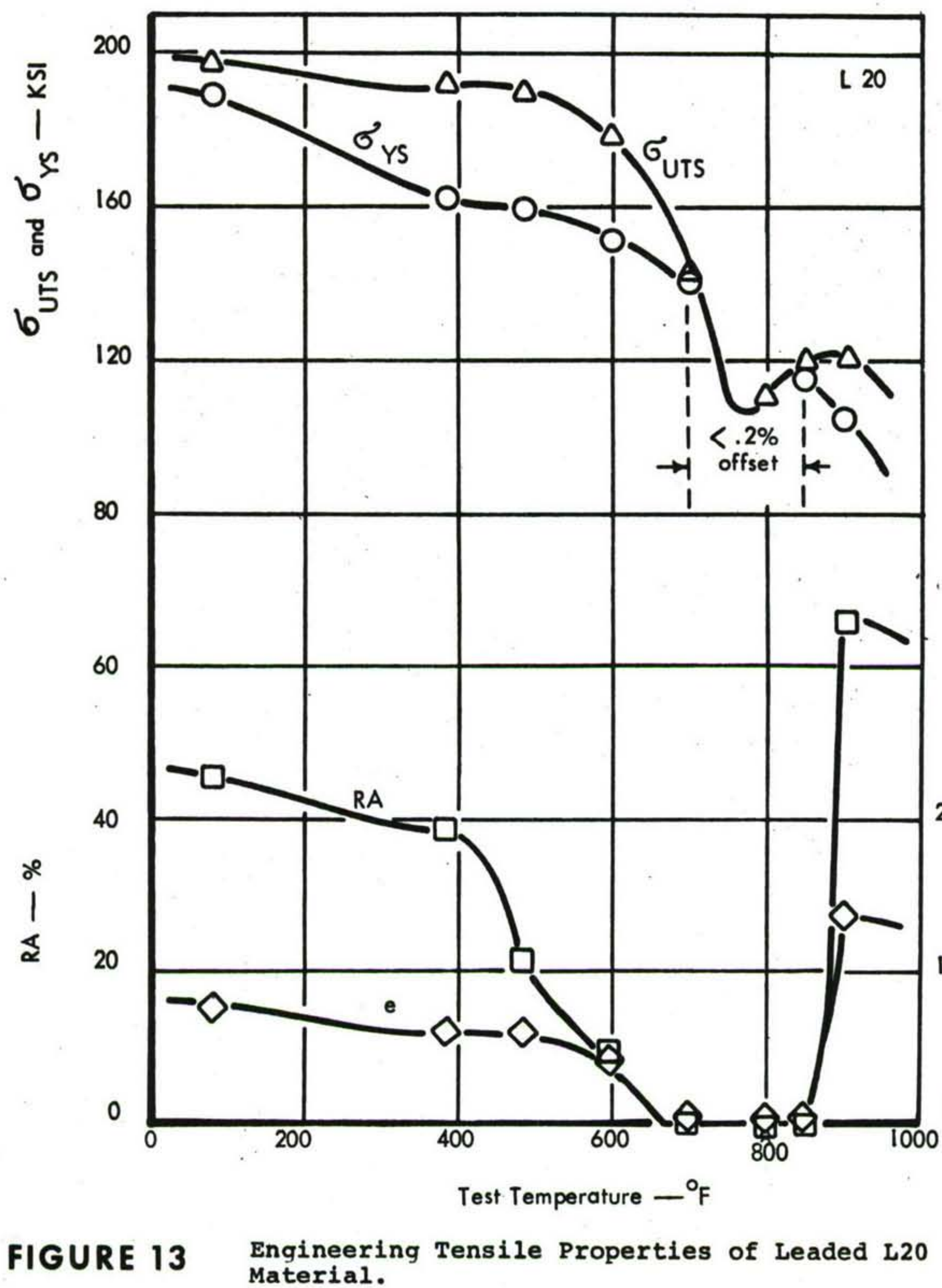
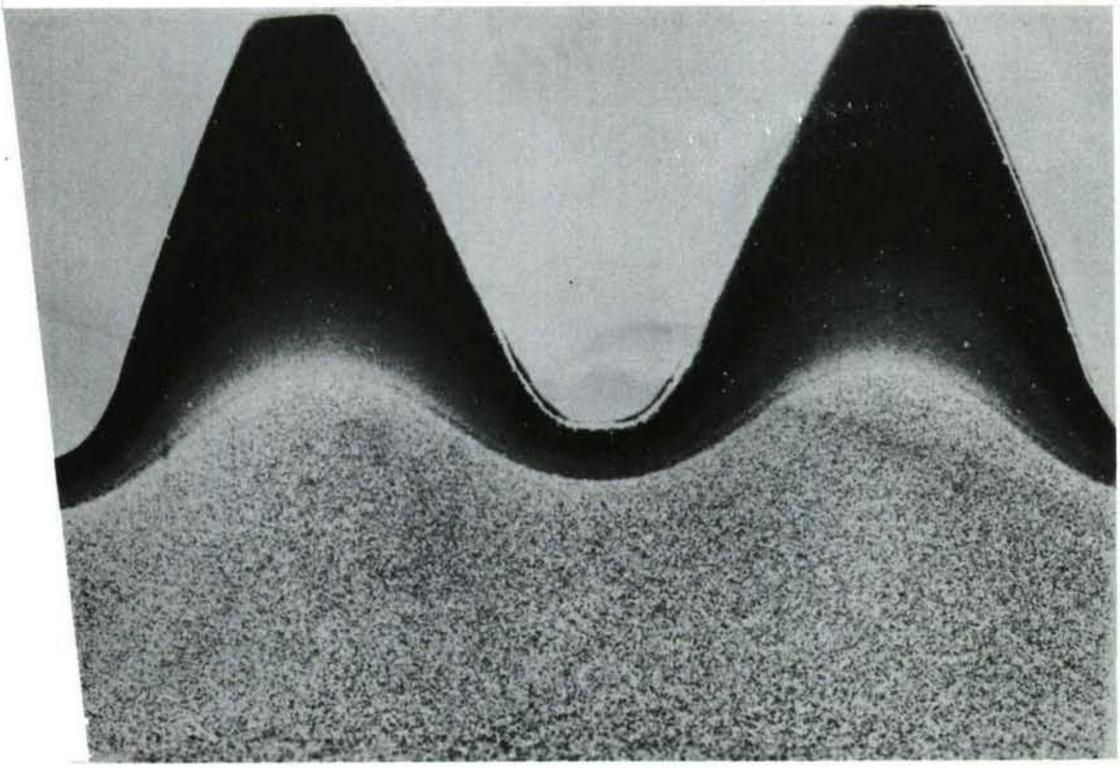


FIGURE 13 Engineering Tensile Properties of Leaded L20 Material.

TANK FINAL DRIVE GEAR

FIGURE 14

ENLARGED GEAR CROSS SECTION (NITAL ETCH)



(SECTION TAKEN ACROSS TEETH
MIDWAY BETWEEN GEAR FACES)

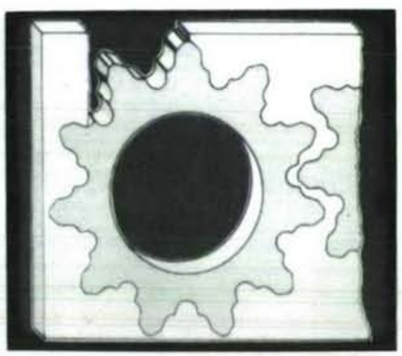
FIGURE 15

GRAPHITE MOLD

PRECISION CASTING OF FINAL DRIVE SPROCKET

PRESENT METHOD of MANUFACTURE:

1. FLAME-CUT FROM PLATE STOCK.
2. HEAT-TREAT TO REMOVE EFFECTS OF FLAME-CUTTING.
3. MACHINE TEETH CONTOURS, BORE CENTER HOLE, MACHINE CENTER HOLE SEAT, AND DRILL ELEVEN BOLT HOLES.
4. FLAME-HARDEN TEETH.



363 LB. PLATE PER SPROCKET ←

• SPROCKET FABRICATED FROM PLATE STOCK

THE PRECISION CASTING METHOD:

- 1. PRECISION CAST TO FINAL DIMENSIONS IN GRAPHITE MOLD.
- 2. BORE CENTER HOLE AND FINISH MACHINE CENTER HOLE SEAT.
- 3. FLAME-HARDEN TEETH.

	PRESENT SPROCKET	PRECISION CAST
MATERIAL	SAE 1345	SAE 1345
WEIGHT OF STOCK	363 lb.	195 lb.
WEIGHT OF FINISHED SPROCKET	94 lb.	94 lb.
SCRAP MATERIAL	269 lb.	101 lb.
FINISHED SPROCKET COST	$75.00	$15.00

ESTIMATED SAVINGS PER SPROCKET — $60.00

FIGURE 16

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13. ABSTRACT

Materials engineering requirements peculiar to tank-automotive equipment can be related to significant basic application factors wherein material suitability can be judged. These factors include weight, service durability, utilization, cost and ballistic integrity. Examples of prior and current development and application programs are described to demonstrate the importance of total materials analysis in tank-automotive equipment for achieving greater reliability, manufacturing simplicity and lower cost. Some of the topics covered are aluminum armor, explosive welding, explosive forming, application of leaded steels, and design around brittle fracture.

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DESIGN CONSIDERATIONS						
LIGHTWEIGHT METALS APPLICATION						
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ALUMINUM ARMOR						
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